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Path Towards Cognitive Radio Based 5G

M.H.Siddiqui[1], K.Khurshid[2], I.Rashid[3], A.A.Khan[4]

[1,2,3,4]National University of Science and Technology (NUST), Islamabad, Pakistan

[2]kiran.khurshid@yahoo.com

Abstract- Fifth Generation (5G) and Cognitive Radio (CR) are considered to be the future advancements in wireless technology. The ever increasing number of smart network devices may obsolete latest 4G technology for handling bandwidth allocation to a large number of smart devices. To meet with this challenging need for rapid and efficient data transfer over such devices, requires next generation mobile technology. 5G technology is anticipated to offer appropriate solutions to such issues in literature. High data rates can be achieved by using 5G, however, to make such futuristic technology realistic, is a real challenge. This challenging goal can be achieved by efficient utilization of the bandwidth in allocated spectrum. CR is an intelligent radio which has inherent adaptive procedures. It reuses the frequency when primary user is absent and works on principle of dynamic frequency allocation. CR is one of the key enabling technology for 5G networks which allows nodes to evaluate and manage underused licensed channels. It has brought benefits to a CR based 5G cellular networks which include ability to adapt dynamicity of a network, deals with the spectrum scarcity issue and operates in heterogeneous environment. It also provides intelligent solutions and self-governing capabilities to assist 5G key functions especially in smart beamforming. In this paper we present numerous benefits of 5G technology, enabling technologies of 5G, its challenges and proposed solutions. Furthermore, CR alongwith spectrum sensing techniques are also discussed in detail. Finally, CR based 5G technology is investigated with the view to explore both technologies jointly and to present a comprehensive overview which will invigorate new research initiatives in this exciting field.

Keywords- Wireless Communication, Fifth Generation, Cognitive Radio, Cognition Cycle, Spectrum Sensing, Resource Allocation, Enhanced Cognitive Radio Networks.

I. INTRODUCTION

Mobile wireless technology commenced its journey towards revolution and development since 1970. The cellular communication industry has witnessed a massive growth and technological advancement in the last few decades which can be classified into different generations from 0G to 5G. Large scale wireless communication has been made possible only due to the cellular concept presented in 1G. Soon after 1G, 2G was introduced in which the old analog technology was replaced by digital technology, which considerably improved the wireless communication. In addition to voice, data communication was also introduced in 3G. 4G technology provides an ultra-broadband network, meeting with the latest network equipment requirement. However, 4G cannot handle the ever-increasing rapid advancement in smart network devices, hence, adversely affect the overall network load efficiency. The solution to the problem through which data transfer becomes more efficient and faster, is the next generation network technology, viz: 5G. In 5G, existing wireless and wired networks will be brought together into all internet protocol high performance worldwide network. 5G mobile network technology is based on CR, whereas CR is the backbone of 5G mobile network and offers best solution for 5G mobile network. CR offers efficient usage of limited spectrum resources and meets ever increasing demands for wireless networks. CR is also known as an extension of software define radio (SDR) which provides the opportunity to re-use the frequency once primary user (PU) is not present. To reap the benefits of CR based 5G technology, adequate knowledge of 5G as well as CR is required. In this regard, the main focus of this paper is to provide a comprehensive survey on CR based 5G technology. Besides this, it also presents an overview of CR and 5G technologies, some enabling technologies of 5G, 5G challenges with their proposed solutions and spectrum sensing techniques of CRNs in order to relate spectrum exploration issues toward 5G.

CR can be completely integrated with the 5G wireless access network as it provides the opportunity for interconnection of existing wireless network in an operable way. In literature, a wide variety of work on mobile generations is available, however, this paper briefly describes the evolution of mobile telephony standards and advancement in technology.

The rest of the paper is structured as follows. In Section 2, literature review on CR and 5G, is presented. Section 3 briefly presents the evolution of wireless communication generations. Section 4 discusses 5G concepts and its major improvements as compared to 4G, challenges faced by 5G and their proposed solutions. Section 5 presents the overview of CR and CRNs alongwith spectrum sensing techniques. In Section 6, detail review of CR based 5G technology from some recent work, is presented. In Section 7 conclusions are presented.

II. Literature Review

This research paper highlights two promising technology i.e. 5G and CR. Researchers have already contributed considerable work on both fields. However, 5G using CR is the most recent domain and still has a room to be explored, in the field of research. It includes areas for integration of CR with 5G, algorithms related to the implementation of CR with 5G. In each of the areas, there exist tremendous amount of work, however this paper encompasses only survey of basic research in recent past. It is generally believed that the future 5G network will be designed to fulfill a huge number of stringent requirements as far as cost, uniqueness and number of associated smart devices are concerned. System that can meet these requirements is only intellectual radio i.e. CR by negating all underutilized technologies. After the inception of 5G many researchers have taken 5G as the solution of all the future problems related to wireless communication network. Hence, many researchers in their papers proposed various inherent benefits of 5G. Different mobile generations are discussed in [1]– [7] and owing to the quantum of data traffic, it is expected that 4G will be used up to few coming years only. This survey paper will be one of its kind reviewing the recent trends about the use of CR based 5G. Researchers have already proposed several features, requirements and improvements particularly in terms of high data rate in 5G. Specific protocols for each of the OSI layer [6] have been proposed basing on earlier research papers works. In different research papers [8]- [12] the major focus of the authors was physical layer and application layer while suggesting some protocols and services particularly at physical layer.

CR was introduced as a new paradigm in 1999 as an extension of SDR. This idea was also proposed in paper [13] for an efficient use of available resources. Author also proposed a new language, viz: RKRL (radio language representation language) for communication between different network devices. However, author's complete CR remains futurist concept where ubiquitous cognition is a part of all the devices and applications which caters our needs. One of the major contribution of cognitive radio, is its use in spectrum sensing in which researchers [14]- [16] allocate spectrum with the help of data collected from physical layer. Simon Hykin in his paper [17], defined CR, as an intelligent wireless communication system which deals with three fundamental cognitive tasks i.e. radio-scene analysis, channel-state estimation and predictive modeling, and lastly transmit-power control and dynamic spectrum management. Author also presented the apparent behavior of CR. During the review and survey of the literature, it was manifested that there is little work done about integration of CR with 5G. However, there exist research work [18]- [21] in which researchers not only discussed the common features of both the technologies but also discussed about the use of CR into 5G.

Cognitive radio network (CRN) is prone to various malicious attacks. The two types of basic users in CRN, are licensed or primary user (PU) and unlicensed or secondary user (SU), however there is yet another unwanted user which is known as malicious user. Malicious user breaks the agreement between PU and SU. A user, which is not trustworthy, becomes a potential risk. Security mechanism is essential for the successful deployment of CRN [22] and its arrangements are necessary for next generation wireless communication networks.

However, security issues related to CRN are not discussed in this paper

III. Journey Towards 5G – An Evolution

Dawn of cellular technology brought new revolution in wireless communications. Through cellular technology re-allocation of frequency band is possible which, in turn gives features of reusability of frequencies and saves energy. Wireless access generations are illustrated in Fig.1. Wireless communication commenced with 0G. 0G technology is also known as analog signal for communication and it was based on public switched telephone network (PSTN). Those mobiles did not support the handover feature. 0G is also regarded as pre-cellular mobile telephony technology. It was forerunner of 1G, hence, is known as 0G. There were many technologies employed in 0G systems. These systems were primarily used only for voice communication. Technologies having better or improved features as compared to basic 0G technologies were termed as 0.5G.

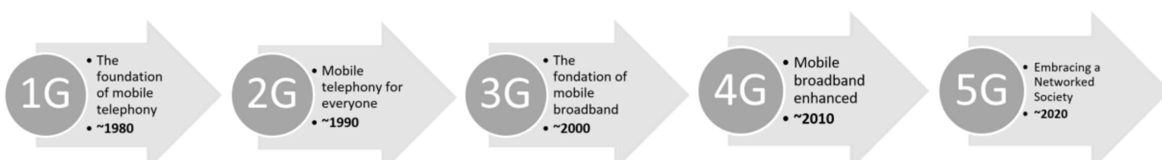

Fig.1: Generations of Cellular Mobile Communication [23]

First time cellular technology was introduced and deployed in 0.5G mobile technology. In 0.5G, network was divided into multiple cells also known as zones of size 30 KMs each. However, rest of the features were almost the same as of 0G.

1G was introduced with analog cell phones in 1980 and is the first generation wireless (cell phones) telephone technology [5]. The first cellular system became operational in 1979 in Japan (Tokyo) by Nippon Telephone and Telegraph (NTT). Analog systems were introduced in Europe in 1980s including Nordic Mobile Telephone (NMT) and Total Access Communication System (TACS) which were the most popular systems amongst all. These systems could not intercommunicate and International communication was not possible with these systems, hence, it was considered as the major limitation of this generation. However, all such systems had handover and roaming features and capabilities. First generation has poor voice links, low capacity, unreliable handoff and was unsecured, hence prone to undesirable interception.

In early 1990s, 2G wireless cellular communication based on digital technologies was introduced. It was introduced in Finland in 1991. It rendered the features like text messages, picture messages and multimedia messaging service (MMS). 2G offered first time secure environment of communication for both sender and receiver. A digitally encrypted text message was introduced which could only be received and read by intended receiver. Digital mobile access techniques like time division multiple access (TDMA) and code division multiple access (CDMA), were also introduced in 2G mobile communication systems.

Group Special Mobile (GSM) has been started from Europe and was the first 2G system. GSM is one of the most acceptable standard out of all the mobile technologies in the world. It enables subscriber to roam around the world. Latest technologies based on GSM system, had emerged which lead this generation to step further ahead and introduced 2.5 generation systems.

General Packet Radio Service (GPRS) is an extension of Second Generation (2G) network to enhance the data rates supported by these networks while maintaining the required capacity. Second and a half Generation (2.5 G) is an informal term which is used to describe 2G systems having packet switched domain feature in addition to circuit switched domain.

Enhanced data rates for GSM evolution (EDGE) is an extension to 2G and 2.5G networks. EDGE superseded the GPRS technology which operates in GSM networks. If the carrier implements the required upgrades with GPRS deployed on it, then it can operate on any network. EDGE technology allows fast data transfer and is termed as an extended version of GSM. EDGE (part of 3G), is a radio technology and it is mostly used over GSM due to its flexibility to carry packet switch data and circuit switch data. One of the glaring advantages of using EDGE is that it does not require additional software or hardware. It is an exploitation of the technology by getting fast data rate without paying any additional charges.

After an apparent demand to get away with the differentiation between wireless and fixed networks, the concepts of internet/ intranet, telecommunication and the advent of virtual office, were considered as future challenges. The concept of globalization becomes more conspicuous after introduction of new communication systems. It brought all offices, home applications and services under one roof, hence, a challenge for 3G communication system. Since in the market today, there are variety of communication systems available for the end user, so there was a need to bring all players together on one commonplace for future communication systems.

However, keeping in mind the heavy investments involved in existing systems, it was recognized to develop standards which could accommodate the backward compatibility and should provide the common framework to all players.

3G is the technology which superseded 2G and preceded 4G technology for mobile communication. International Telecommunication Union (ITU) has implemented global frequency band in 2000 MHZ range. 3G technologies offer more advanced services without compromising the network capacity while maintaining improved spectral efficiency.

High-Speed Downlink Packet Access (HSDPA) is a mobile telephony protocol and extension of 3G which is known as 3.5G. It allows higher data rates for universal mobile telecommunication system (UMTS) based 3G networks. It is a packet based data service in WCDMA with higher transmission rate up to 8-10 MBPS whereas in Multiple-Input Multiple-Output (MIMO) systems the data rate reaches up to 20 MBPS. Hybrid automatic request (HARQ), MIMO, adaptive modulation and coding (AMC) are few implementations of HSDPA.

High-Speed Uplink Packet Access (HSUPA) is a UMTS/ WCDMA uplink technology and pertains to the technologies beyond well-defined 3G wireless technologies. It is also known as 3.75 G. The HSUPA and HSDPA are related to each other and are complementary to one another.

The term 4G is all about the concept of commonplace for operation of various networks with high data transfer speed from 0-100 MBPS (with moving at the speed of 60 kmph). However, the data transfer will be of 1GBPS minimum (in case of stationary). There are few inherent 3G problems of deployment and few limitations pertaining to performance and throughput. Hence, 4G is the concept initiated by the researchers to further move beyond the limitations of former system. Internet can be accessed through mobile device with the help of EDGE, GPRS, WAP, Wi-Bro, Wi-Max and Wi-Fi in 3G. If mobile device is moving to the place where inter-operability among these technologies are

Generation	1G	2/2.5G	3G/3.5G	4G	5G
Time Period	1970-1984	1990-2004	2004-2010	2010 onwards	Soon (probably 2020)
Data BW	2 Kbps	14.4-64 kbps	2 Mbps 14.4 Mbps	200 Mbps to 1 Gbps for low Mobility	1 Gbps and higher
Standards	AMPS	2G: TDMA, CDMA, GSM, 2.5G: GPRS, EDGE, 1xRTT	WCDMA, CDMA-2000 HSPA	Single unified standard WiMax LTE WiFi	Single unified standard
Technology	Analog Cellular Tech	Digital Cellular Tech	Broad BW CDMA, IP Tech	Unified IP and seamless combination of broadband, LAN/WAN	Unified IP and seamless combination of broadband

Table 1: Comparison between various Mobile Generations

required to be obtained, then it will be stuck. The only solution to the problem is 4G, with which one can access all the aforementioned technologies while moving from one place to another.

Technologies before the concept of 4G or pre-4G are an extension of 3G with more bandwidth and services. 4G was expected to render better quality audio and video live streaming over Internet Protocol (IP). It is designed to provide inter-operability and support all the latest applications which were not supported by the previous generations. Subsequently, this technology can be further modified with the ever-increasing demand and requirement of future e.g. the concept of massive MIMO can be incorporated with the 4G concept through which one can achieve the spatial efficiency as well as high speed data rate. Comparison between various mobile generations are shown in Table 1.

IV. Fifth Generation Technology (5G)

The term 5G was introduced by the researchers for the future mobile communication standards beyond the 4G. In mobile technology, wireless communication is considered to achieve perfect level of communication after introduction of 5G networks. Cable networks have now become obsolete after the extensive intake of mobile communication tools. Former wireless technologies provide solutions which pertains to the easy telephone and data sharing. 5G has given a new dimension to the wireless mobile communication technology by making it really mobile. It has revolutionized the means of communication by using cellular phones with very high bandwidth. Users have become more aware about the features and services offered by the mobile telecommunication companies, than ever before. Hence, 5G can cater all the user requirements and demands related to the mobile services in near future. Due to the high investments in current infrastructure of network technology, it is not an easy job to shift from 4G to 5G abruptly. However, to achieve the features and services as envisage in 5G concept, the current infrastructure of network technology is required to be changed either by redefining the standards or by replacing altogether. Various aspects related to the shifting from 4G to 5G are appended below [1], [3]– [7], [24]:

- *Network Infrastructure* - To achieve end to end quality service in 5G networks, both IP based system and voice would be embedded into a single unit.
- *Data Encryption* - In encryption, data is changed into unreadable format which can only be decrypted by sender or authorized receiver, whereas no third party can understand it. Owing to the requirement of new infrastructure as proposed for 5G, maintaining of data encryption would be a real challenge. However, as an interim measure, 5G can follow the data encryption principles being followed in LTE, whereas encryption can be applied for user and device identification and authentication.
- *Denial of Service (DoS)* - 5G is prone to Denial of Service (DoS) attack, due to its inherent environment. Massive signals of uncountable devices are active at any instant of time which encourages malicious users to launch an attack by sending signals on behalf of others. It is very difficult to detect true sender in 5G scenario.
- *Quality of Services (QoS) vs Network Architecture* - The aim of any generation of network is to provide quality of services to its subscribers. Hence, for this purpose the complete network is divided into various layers. The performance of the upper most layer is very

vital to provide better services to the user. This layer is directly in touch with the user. Bug free layer is required for proper functioning of 5G application.

- *Tradeoff between Finance and Services* - 5G environment may consist of multiple networks with different services and features. Users would require to pay the charges of each network and service, which results into heavy amount to be paid by the user. It will be a challenge to maintain these details and bills in such networks.

4.1. 5G-Challenges and their Proposed Solutions in Recent works

- *Data Rate* - 5G is expected to have data rate 1000 times greater than that of existing 4G network. Data rate as desired for 5G networks, is also essential in achieving low-latency communications. To overcome this challenge, number of solutions and techniques have been discussed in literature. In [25] various techniques such as use of mm-waves, concept of massive-MIMO, beamforming and use of small cells, are discussed to enhance the transmission speed and overcome the scarcity of spectrum. However, in [26] the concept of Terahertz (THz) communications is examined which uses the band 0.1-10 THz. Such communication has abundant of spectrum resources as compared to the resources associated with the mm-wave band. In THz communications, benefits of electromagnetic and light waves can be achieved altogether. It is anticipated that THz communication will offer multi-Tbs transmission in wireless communications. Two types of THz physical-layers transmission has been specified by IEEE 802.15.3d [27] in the lower frequency band to obtain 100 Gbs data transmission. Hence, by using THz communications number of advantages [6G] can be achieved such as large spectrum resources, integrating large number of antennas to get multiple beams and highly directional transmission which prevent inter-cell interference. Many techniques such as sub-THz and visible light links, densification of RAN, Network Slicing, Cloud-RAN, backhaul networking, beamforming, cloud implementation, edge computing and making use of front haul links are investigated in [25], [28] to achieve desired spectral efficiency and data rate. In [29], [30], various techniques to attain desired level of data rate and spectral efficiency for 5G is thoroughly explained.
- *Response Time* - Owing to the requirement of 5G network and future demand especially in the field of virtual reality and online services, the latency in 5G should not exceed 1ms. The time 4G network takes or latency in 4G network is up to 15ms which certainly requires improvement. To mitigate the latency problem and to improve the response time as desired for 5G networks, number of studies have been carried out to investigate the matter [31]-[36]. The recent techniques especially ML is applied to signal processing, spectrum sensing and allocation and spectrum mapping [37] which increases the response time of the system. The concept of photonics-defined radio will change the paradigm of future communication system [38]. In [38], AI for 6G is evolved through combining photonics defined radio with ML. Combining photonic technology with AI to achieve low latency for future 6G infrastructure is discussed in [29]. Another concept of new frame structure for 5G with low overhead and less latency is discussed in [39]. An ultra-reliable low-latency communication (URLLC) for autonomous vehicular networks in 5G cellular communication system is proposed in [40]. The proposed scheme evaluates the combined effect of reliability and latency on 5G networks. Models of reliability and latency are discussed and their joint function is proposed. However, on the basis of their performance analysis and to mitigate their conflict in 5G networks a network slicing solution is also proposed. The network slicing technology offers efficient radio resource utilization of wireless networks and provides solution to multiuse scenarios in shared network infrastructure.
- *Power/ Energy Conservation* – In 5G networks, long life of battery is an essential requirement, therefore, it will be enhanced ten times more than that of the current 4G networks. It is also anticipated that energy and cost will be reduced in 5G networks. Energy efficiency is an essential attribute of 5G communication systems. Various energy-efficient techniques related to 5G networks have been reviewed and discussed in literature. In [41], [42], authors reviewed the energy crunch through economic and environmental concerns. Approaches to enhance the energy efficiency are grouped in four broad categories, such as network planning and deployment, energy harvesting and transfer, resource allocation and finally hardware solutions. In [41], an exhaustive survey of most modern work done focusing on the energy efficiency of wireless networks. The energy efficiency is measured in bits-per-joule as a performance metric. The paper classifies the work on energy efficient wireless networks into aforementioned four categories based on their focus. Firstly, (radio) resource allocation: The energy efficiency of a communication link has been defined by an expression (equation (2) of [41]). It is a non-monotonic function of transmit power which indicates the presence of a maximum viable transmit power. Secondly, network planning and deployment: It maximizes the covered area per consumed energy through dense heterogeneous networks, and employability of massive MIMO, making BS and nodes sleep to reduce power consumption. Making nodes employ device-2-device communication would also offload networks, e.g. using visible light communication, mmWave cellular or even through local caching to offload backhaul wireless links. Thirdly, energy harvesting and transfer: considering both renewable and radio energy harnessing, it also focuses on work that consider simultaneous transfer of

information and energy to nodes. Fourthly, hardware solutions: evaluating effects of low power amplifiers, simplified transmitters/receivers, cloud based implementation of some of base-station functions in software to reduce BS size and hence power. The paper concludes that optimizing individual aspects would not be able to achieve the target of 1000 times energy efficiency of current wireless systems. Hence, a holistic approach would be needed that could deal with interference, and randomness with new energy models. Another energy efficient scheme is proposed in [43] which exploits the vacation period of the BS. It anticipates the sleep depth period of BS in advance. In this scheme for partial deactivation (sleep depth) and fast activation of the hardware, 5G RAN with dual connectivity (separate data and control plane) is considered. Hence, power consumption is reduced due to on-demand system and this approach is known as control-data separation architecture (CDSA). It has been implemented in 5G RAN standard. This scheme shows that BS consumes lowest power during deactivation (sleep depth) period which results in considerable reduction of energy consumption. In [44] authors proposed nature inspired approach (NIA) for energy optimization in 5G networks. The scheme follows the river formation dynamics (RFD) approach to optimize energy for 5G. An energy efficient Doherty power amplifier (DPA) MMIC for 5G applications along with a beam-forming oriented DPA, are proposed in [45]. An offset line is removed behind the main power amplifier (PA) in the proposed architecture, hence it becomes more compact in size. Energy efficiency in DPA is achieved through an appropriate selection of Z-load and power ratio between main PA and auxiliary PA. In beamforming oriented DPA, energy efficiency is achieved by reducing the number of feedback paths and pre-distorters. In [46], a power efficient scheme is proposed for non-orthogonal multiple radio access (NOMA). NOMA is considered one of the promising schemes for 5G networks. Power optimization is achieved through low complexity power resource allocation scheme for downlink NOMA systems.

• *Integration of Assorted Standards* - Each technology has its own standards. To integrate different engineering practices and standards, require systematic and time consuming approach. A massive advancement in communication technology is taking place where billions of devices are generating enormous proportion of data. However, there is no unified standard for 5G networks for these devices to establish communication with each other. A new structural paradigm or technology shift is required for complete realization of future 5G networks. 5G technology is considered as an essential tool for realization of future IOT associated with machine-to-machine (M2M) communication where billions of devices will be connected. Efforts are in hand to establish a unified standard for 5G networks by 2021 in US, South Korea and China [47]. In [48] software defined network (SDN) and Network function virtualization (NFV) are discussed with the view to analyze generalized solutions for various integrated schemes of 5G wireless networks. The existing gap between certain enhancements and 5G network can be addressed through innovative enabling techniques. An overview regarding 5GS gap analysis and its management is presented in [49]. An overview is presented on passive optical networks (PONs) and their requirements for 5G wireless communication in [50]. Few fundamental changes are also discussed in 5G transport architecture and progress on current standards. Latest studies and innovative techniques related to unified standards for communication devices in 5G networks are presented in [51] - [55].

• *Common Platform* - There is no common platform to regulate various engineering practices. An architecture in terms of common governing body is required. It can provide a common platform for all engineering practices to regularize and resolve their interconnectivity matters. It can also render its services in terms of sharing knowledge. The concept of an operating system (OS) for 5G is discussed in [56] which will act as central unified software platform. It is anticipated that future networks will be too complexed and dynamic to handle by humans. Such scenarios demand automated systems and techniques (virtual machines, ML, AI, etc) to manage and control the future networks. The aforementioned OS will regulate all functions and management issues relating to 5G networks. Requirements for 5G end-to-end measurements through a common platform is also elaborated in [57], moreover, various opportunities are discussed to utilize MONROE platform for 5G networks. Another concept of 5GENESIS is described in [58] which embodies many platforms. These platforms are also termed as 5G testbeds and provide experimentation facilities. In [53] a unified platform for 5G networks is proposed which is termed as control architecture for 5G networks. The proposed architecture broadly encompasses the functionalities of access control and session control. Using access control function, it allows connections through access network through constant signaling technique. Hence, the proposed architecture lessens the reliance on access network. Likewise, the session control function enables session control by constantly sending session requests over various access network. Telecom networks are designed in a hierarchical way, where all traffic is accumulated at a collection point (base station controller) and routed to gateways. To reduce the traffic load on aggregation or collection point, flat IP architecture will be better option. In flat IP architecture subscriber traffic is directly routed from base station (BS) to the gateways. A common IP platform will be emerged after transition from legacy (TDM, ATM) platforms to IP. Super core concept [59] is based on IP platform. All network operators can be connected to single Super Core with massive capacity which is also realization of single network infrastructure. Super Core concept will resolve all interconnecting matters and complexities, which are presently being faced by network operators. By implementing Super Core concept will definitely reduce the number of entities in end to end connections, which will also result in reducing the latency.

4.2 Enabling Technology for 5G

Major modification in existing technologies is required to achieve desired standards for 5G so that it can offer more accurate, reliable, secure and fast data processing. Few of them are appended below [1], [3]– [7], [23]:

- *Enhancement of Network Density* - Densification can be achieved through deployment of large number of cells in lesser space. It is one of the challenges faced by researchers nowadays. However, deployment of cells within one tenth of square kilometer has already been achieved.
- *Massive MIMO* - After the introduction of MIMO, capacity of the radio link has been increased manifold due spatial multiplexing, by employing multiple transmit and receive antennas. Spatial multiplexing requires the configuration of MIMO antennas and harnesses this feature to get better results. Higher capacity is yet to be achieved after the inclusion of Multi-User MIMO in 3GPP LTE- advanced standard. In Massive MIMO technology, number of terminals is lesser than the number of antennas. Hence, better standards and features are expected to achieve once incorporated with the standards of 5G technology.
- *Millimeter (Mm) Wave* - Transmitting large amount of data is one of the important uses of millimeter waves. In all wireless communication technologies, specific range of frequencies and wavelengths are used. It has been found that 30-300 GHz are freely available bandwidth which makes the total available spectrum 200 times larger than that of currently used frequency in this range.
- *Direct Device to Device (D2D)* - Network devices or base stations receive thousands of requests simultaneously. Exchange of data between the two devices without involving network devices increase the data transfer speed whereas reduces the load on the network devices. Dealing with the heterogeneity of network is essential for such purpose for which many protocols have been decided.
- *Full Duplex Wireless* - The capability which enables both sides simultaneous data transmission over same frequency band is known as full duplex. The benefits of full duplex wireless include security, latency improvement and increase of physical layer capacity.
- *Internet of Things (IOT)* **-** IOT is a worldwide network which uses the standard communication protocols. It also employs diverse technologies to gather and process the huge amount of data from heterogeneous devices. It is anticipated that in next two years more than 50 billion devices will be connected as constituent of IOT [60] and this number may increase more than 75 billion devices by 2025 [61]. Consequently, massive data will be generated which requires certain features which are attributes of an efficient communication system such as quality, capacity, speed, reliability and heterogeneity. However, IOT devices lack in computing resources which is their intrinsic limitation. Hence, to overcome this limitation, tasks of numerous applications are required to be offloaded to computing systems for further processing. This arrangement increases the latency and creates congestion in the IOT networks [62]. A novel paradigm 5G intelligent IOT (I-IOT) has been proposed in [60]. The concept of 5G I-IOT paradigm is to congregate three major components which include intelligence, internet and things. It is anticipated that 5G will be the backbone of future IOT devices with the advancement of wireless technologies. An eight layered architecture has been proposed in [61] to cater for the connectivity of billions of IOT devices through 5G technology. A concept of IOT applications using 5G edge, is proposed in [63] to mitigate the computational problem related to IOT networks. The basic idea is to exploit the capacity (in terms of storage) and computational potential of the edge devices connected to the internet and placed in-between the devices. In [64], authors discuss the use of AI and CR for an intelligent usage of spectrum in IOT base 5G networks. In proposed approach, Kipling's method is used for intelligently and efficiently managing the network resources in IOT based 5G networks. The 5G networks are embodiments of an anticipated IOT application as it promises the massive bandwidth. 5G can contribute significantly to the IOT networks by connecting billions of IOT devices (things) to produce future gigantic IOT. Presently, IOT systems are designed for specific application domain, however IOT is developing expeditiously with latest technologies especially with the concept of correlation between smart devices and smart environment. The industrial IOT (IIOT) has also undergone tremendous development in order to produce new products, their solutions and transforming the business models [65]. 4G (LTE) and 3GPP are the communication techniques which are most popular for interconnectivity of the IOT devices. However, recently extensive work has been done for finding solutions to incorporate 5G with IOT networks. In [66], a management scheme is proposed to access IIOT based 5G new radio (NR) standalone system. The proposed scheme offers low latency rate and provides massive machine type service for establishment of communication between user and 5G NR standalone system. In [67], authors investigate the security architecture in order to address the vulnerabilities of IOT systems. The proposed approach uses analytic hierarchical process (AHP) to evaluate

the ten existing models of IOT in order to design the best possible security model for future IOT systems.

- *Artificial Intelligence (AI)* - In 5G networks, numerous mechanisms related to service provision and transmission take place simultaneously. AI enables 5G to adjust its parameters and configurations rapidly and intelligently. Subsequently, it reduces overall latency rate and enhances the reliability of the communication system. Ever growing technologies in the field of wireless communications demand efficient solutions for radio resource management (RRM). The requirement of the configuration parameters in 5G is expected to be much more as compared to the 4G node. There is a need to enhance the intelligence of such architecture to meet the future demands of the communication systems. In [68] software defined networking (SDN) architecture for 5G is discussed which uses centralized logic for routing and networking functions. However, with only low level configuration commands, it is extremely hard for network hardware to manage various makes and types of network devices, ever changing policies and its implementation. An intelligent mechanism or techniques like AI, machine learning and control theory etc., are required to deal with such challenges for self-organization of the network [69]. A cellular network architecture supported by AI is discussed in [70], where an AI-controller is placed in an open network operating system (ONOS). AI-controller manages communication between RAN, core network (CN) and SDN controllers. Another possible implementation of AI in 5G networks is presented in [71] through CogNet scheme. AI applications enhances the adaptability of the network which enables it to adjust and reorganize itself with the constantly varying future demands.
- *Beyond 5G (6G)* - 5G technology follows the path of its predecessor and is assumed to be an extension of 4G. Hence, very marginal improvement is expected. With the realization and expected commercialization of 5G, the concept of 6G has become one of the core area for research. There are few countries who have already launched their future strategies related to the 6G technologies. The European Union has launched their three years plan on 6G technologies in September 2017. In China, a study has been started to incorporate the concept of 6G with IOT especially in the fields of virtual reality, medical imaging and sensing. An eight years' research plan, "6Genesis", has been launched in April 2018, as a joint venture between the Academy of Finland, University of Oulu and Nokia [72]. In [73] authors ascertained that commercialization of 6G technology will be started in next ten years. The expected inherent attributes of 6G networks will be ultra-high processing speed, ultra-low latency and massive capacity. It is also anticipated that the data rate of the 6G will be increased by 100 to 1000 times where as capacity will be 10 to 1000 times greater than 5G networks [74]. 6G can be termed as paradigm shift in mobile communication systems which brought revolution in such systems. In [29] authors proposed numerous technologies such as AI, photonics-based CR and holography radio technology as appropriate candidates for 6G systems. Few promising future techniques such as multi-band ultra-fast speed transmission, super flexible integrated networks, multi-mode multi-domain joint transmission and intelligent transmission are described in [30] for future 6G architecture. The authors also discussed some potential challenges for 6G development such as power supply issue, network security and hardware architecture. Possible solutions to such problems are also described in [30]. The concept of data center connectivity through 6G is discussed in [75]. The basic idea is to get benefit from the inherent attributes of 6G technology while ensuring flexibility and adaptability without undermining scalability of the communication network. The concept of quantum machine learning for future 6G communication networks is presented in [76]. The authors discuss the concept of quantum computing (QC), machine learning (ML) in detail. The emergence of their mutual framework known as quantum-ML (QML) is also described with the view to exhibit their collective gains. There exists numerous latest techniques and framework related to 6G technology yet these are not discussed as considered beyond the scope of this paper.

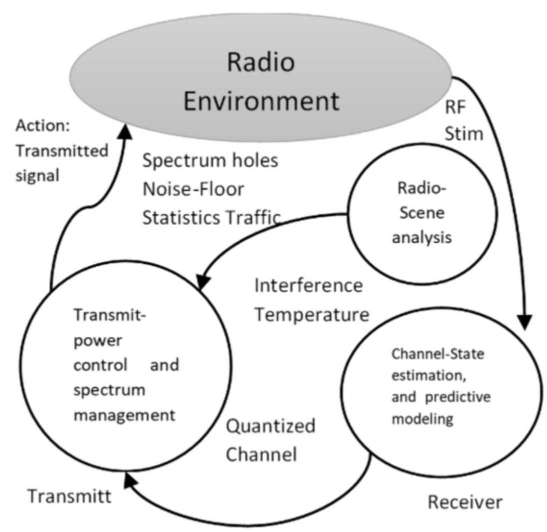

Fig. 2: Cognition Cycle Model [17]

V. COGNITIVE RADIO (CR)

Generally, it is defined as an intelligent radio in which transceivers can be reconfigured and can adapt themselves with the new condition of the network [13]. CR encompasses two major areas of working i.e. Full CR and spectrum sensing. To optimize the network, network parameters are required to be modified which is taken care by Full CR. Spectrum sensing is an essential area of CR which senses the available spectrum for utilization to avoid underutilization of spectrum. CR is the best choice for detection and allocation of available spectrum for an instant which is also known as dynamic spectrum access technique. For optimum utilization of spectrum in CRN, SU can only use the spectrum (at a particular instant of time) when it is free.

5.1. CR-Key Terms

- *Spectrum Sensing* - In CRN the spectrum is sensed by the cognitive terminal after a particular instant of time and switches to best available frequency band.
- *Spectrum Sharing* - Once the licensed user occupies the band, the resources are shared without affecting the adjacent licensed users.
- *Sensing Based Spectrum* - In this technique CR user lower its transmit power after confirmation that licensed user is not using the spectrum.

5.2. Cognition Cycle (CC)

CC is a technique for learning the best solution from the past experience. Almost all AI concepts have been applied to employ CC in CRNs. However, implementation of CC in the perspective of 5G is very limited in literature. The concept of CC is very close the concept of self-organization. The three attributes of self-organization which include scalability, agility and stability, are the inherent characteristics of CC. The concept of scalability is to keep the complexity level to the minimum even if the number of nodes increase in a distributed network. Stability follows limited number of states within an appropriate time interval without oscillation. Agility adapts to the variations in operating domain. Detail working of CC is shown in Fig. 2.

5.3. CR Architecture

There were two basic problems which were faced by the researchers before suggesting the architecture of the CRN. Firstly, any variation done in transmission mode by the device in CRN may leads to the malfunction of algorithm. Secondly, the bandwidth varies due to the move of user having different bandwidth, to another location. Due to these problems, researchers proposed architecture of CR with three basic sub systems. Fig. 3 shows the CR architecture with the following three basic sub systems:

- *Cognitive Unit* - Decision making mechanism depending on provided input.
- *SDR Unit* - Operating environment provided by operating system.
- Component which determines the signal and user characteristics.

5.4. Accesses in CRN

Fig. 4 shows the CRN architecture. There are three types of accesses which are performed by CR:

- *CRN Access* - Sharing of the spectrum is independent of primary network. CR users can access their own base station irrespective of licensed or unlicensed band.
- *Primary Network Access* - In CRN, licensed band can be accessed by CR users through primary base station.
- *CR Ad-hoc Access* - Different cognitive users can intercommunicate through ad-hoc networks over licensed and unlicensed bands.

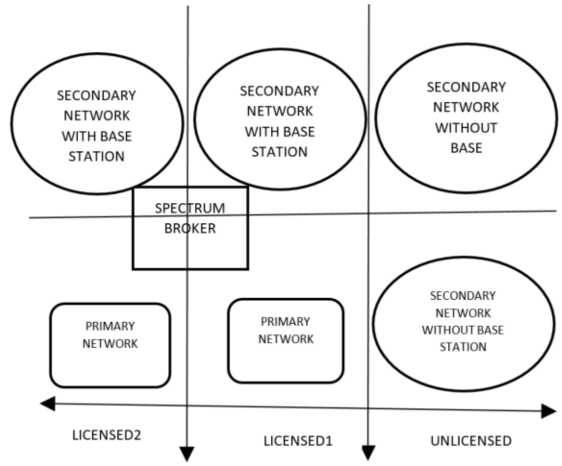

Fig. 3: Architecture of CR

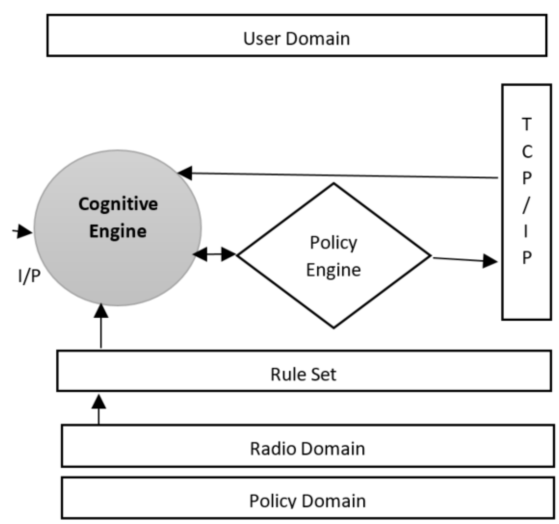

Fig. 4: Architecture of CRN

5.5. Functional Model of Cognitive Engine (CE)

In an introductory paper of CR [24] functional model of an ideal CE having various stages like observe, orient, plan, decide, act and learn, has been suggested. Observe generally, is the first stage in the loop which passes response to another stage in the sequence as shown in Fig.5 [77]. Fig.5 shows following stages of two loops:

- Loop-1 known as Sensing and Adaption loop -

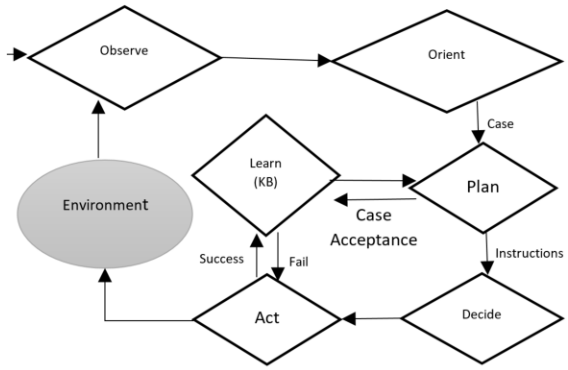

Fig. 5: Cognitive Loop at two levels

Observe, Orient, plan, Decide and Act

- Loop-2 known as Learning loop - Decide, Plan, Act and Learn.

5.6. Building Blocks of CE

- *Modelling System* **-** Observe stage is taken care by Modelling System in cognitive loop and sensing function. It can handle in the form of user, wireless and policy domain. Stable model of the machine is achieved through prior knowledge, identification, integration and abstraction of input information.
- *Knowledge Base* **-** As name indicates, it consists of knowledge through information gathers either manually or from different devices. The knowledge is collected from prior experience and temporary network condition feed.
- *Reasoning Engine* - It is also known as a brain of Cognitive Engine and one of the most important component of entire system. In adaptation loop, it helps in simulation of Orient, Plan, Decide and Act.
- *Learning Engine* **-** It collects all the feedbacks related to the actions taken by the CE along with effects of results. It accumulates it as knowledge and converts it as knowledge base. Due to its vital performance, it is also known as futuristic brain of CE.

5.7 Key Benefits of CR

CR has some advantages over rest of the methods in terms of various parameters like time and space, frequency, modulation and power. Following are few benefits of CR:

- *Efficient Spectrum Management* - The basic purpose of CR is to accept the future challenges like increasing demand of spectrum and provide efficient spectrum management to the users.
- *Higher Bandwidth* - CR can also support the higher bandwidth if it is required by the user.
- *Continuity in Services* - When the condition of the network is not satisfied, it ensures the continuity in services by avoiding sudden drop through graceful degradation of services.
- *Quality Assurance* - Quality assurance is the basic requirement of any network, so is the case of CR. To ensure quality of services few parameters like data rate, latency and cost are the indicators which can determine the availability and reliability of any wireless networks.
- *Independent of Hardware Platform* - CR is independent of hardware platform and supports the hardware capable of handling different types of software.

5.8. Spectrum Sensing Techniques in CR

It is the process of finding vacant radio spectrum in the absence of primary or licensed users. Effectiveness of CRN depends on an efficient spectrum sensing. Spectrum opportunity found by CR, is based on proactive or periodic and reactive or on demand approach. There are two possibilities to find either PU's receiver spectrum operating range or to detect PU's transmitter. However, receiver detection is not possible, hence, PU's transmitter detection based sensing is used. Spectrum sensing is generally classified into two sensing techniques, viz: cooperative sensing and non-cooperative sensing. Centralized and decentralized schemes pertain to Cooperative sensing where as non- cooperative involves primary user transmitter detection.

5.8.1 Non-Cooperative Sensing

Non-cooperative spectrum sensing is used by secondary users to detect the primary user transmitted signal through local observations and measurements. A binary hypothesis model is used for analysis of signal detection,

$$x(t) = \begin{cases} n(t), & 0 < t \le T \quad Ho \\ hs(t) + n(t), & 0 < t \le T \quad H1 \end{cases} \tag{1}$$

where, x (t) represents received signal, n (t) additive white Gaussian noise, s(t) primary user transmitted signal, h the channel gain, H_0 represents absence of primary signal and H_1 represents that the spectrum is occupied. Various methods in non-cooperative spectrum sensing are as followed:

- *Energy Detection Method* - Due to the non-coherent detection approach, SUs generally do not know the PU's signal attributes. In this technique, the strength of received signal of transmitter is compared with the level exclusively set for detection. Time division energy detection is based on Urleowitch detection which proposes that priory measured signal and noise variance can be measured in AWGN [78]. Input signal *y(t)* first passes through Band Pass Filter (BPF) with central frequency f_0, and bandwidth *w,* then transfer function is given by:

$$H(f) = \begin{cases} \frac{2}{\sqrt{No}}, & |f - fo| \le w \\ 0, & |f - fo| > w \end{cases} \tag{2}$$

where, N_0 is one sided noise power spectral density which helps in normalizing false alarm and detection

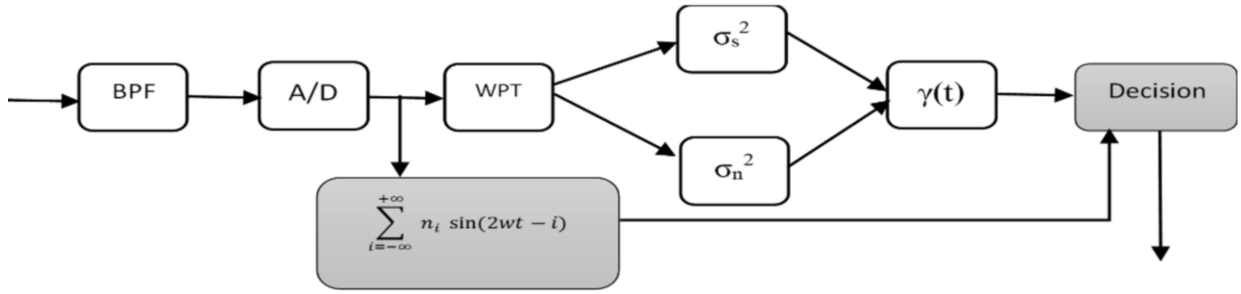

Fig. 6: Flow of working in energy detection based sensing

problem. After passing through BPF, signals get squared and then finally signals are integrated in period of time slot 'T', in comparison with received signal λ.

$$\begin{cases} H0: \; y(t) = w(t) \\ H1: \; y(t) = x(t) + w(t) \end{cases} \quad (3)$$

Where, H_0 shows no signal transmitted and H_1 represents signal transmitted. x(t) is unknown deterministic transmitted signal whereas w(t) is AWGN with zero mean and variance (σ_2= wN_0). SNR is expressed as $\gamma(t)= \sigma s_2/ \sigma n_2$ where σs_2 represents variance of signal and σn2 represents noise variance. Fig.6 shows the flow of working in energy based sensing. Noise signal can be constructed with the help of Shannon's sampling formula as:

$$n(t) = \sum_{i=-\infty}^{+\infty} n_i \; sin\,(2wt - i) \quad (4)$$

Where, sin(x) = $\sin\pi x/\pi x$ is a normalize sin function and n_i = n(i/2w) is ith noise sample. Test sample is calculated as:

$$V = \int_0^{\tau} (n(t))^2 \; dt \; \approx \; \frac{1}{2w} \sum_{i=1}^{2\tau w} n_i^2 \quad (5)$$

- *Waveform Based Sensing* - This sensing method is based on pattern recognition. There are many patterns like preambles, successive transmitted pilot patterns and spreading sequence etc. that exist. These patterns are used to sense whether received signal is the copy of itself [79]. Presence of PU can be detected by using some derivation as explained below:

$$y(n)=w(n)+s(n) \quad (6)$$

where, s(n) is the signal which is required to be detected, w(n) is a sample of AWGN and n is a sample index. For the energy detector, decision matric is written as:

$$M = \sum_{n=0}^{2N} |y(n)|^2 \quad (7)$$

Where, N denotes the size of observation vector

$$M = Re[\, y(n)s*(n)] \quad (8)$$

Where * is a conjugation operation. In the absence of PU, metric value is:

$$M = Re[\, \sum_{n=1}^{n} w(n)s*(n)] \quad (9)$$

When PU is present then matric will be

$$M = \sum_{n=1}^{N} |s(n)|^2 + Re[\, \sum_{n=1}^{n} w(n)s*(n)] \quad (10)$$

values of M are compared with the threshold value known as λE and then presence and absence of PU is detected. Experiment result shows that waveform based sensing can perform better than energy based sensing in terms of reliability and convergence time [79]. Overall performance will increase with the increase of known signal patterns.

- *Cyclo-Stationary Sensing* - SU operating in the same frequency band, knows the attributes of PU which includes data rate, carrier frequency and type of modulation. The presence of legitimate user is detected by the characteristics of received signal due to periodicity or recurrence. In this type of detection, for normal execution fast fourier transforms (FFTs) are used. Overall system performance is likely to be degraded due to the presence of nonlinear RF.
- *Matched Filter* - In this method prior knowledge of signal information being used by PU is required. Input signal is compared with already known signal for detection. It is also called coherent detection method. Output SNR is increased for input signal by optimal detector. Due to the presence of timings and frequency offsets, the performance of this type of detection is degraded.

5.8.2 Cooperative Sensing

There are few challenges in non-cooperative spectrum methods which include requirements of high detection sensitivity, exploitation of vulnerable PU's receiver by SU, complexity and difficulty in terms of sensing in multiuser environment etc. [15] [78]. In cooperative sensing, multipath fading and shadowing effects pose major limitation. There are few Sus which are in fading region where as few are with stronger signal strength in the spectrum environment. In cooperative sensing, SUs share their details including channel occupation and CR information. Reliable spectrum information can be acquired through the combination of both information. The popular sensing techniques in cooperative sensing are Centralized sensing and Distributed sensing. In Distributed sensing approach, data is sent through neighborhood CR users for decision of sensing information. Whereas in case of Central sensing, fusion center decides the unused spectrum after the analysis of sensing information received from cooperative SUs. Issues related to synchronization and the sensing delay are few challenges for cooperative sensing techniques in Crs.

VI. CR Based 5G – A Review From Few Recent Works

In mobile generations, there are two types of network architectures which include centralized particularly in early mobile generations and other is cluster approach in later mobile generations. There is a need to work in all forms of network architectures. 5G mobile technology based on CR, inspired researchers to use both simultaneously as it supports both integrated and cluster architecture. It also shows the similarities between 5G and Cognitive Radio [10]. In mobile communications, transmitting and receiving node is called terminal. 5G network consists of many heterogeneous mobile networks, hence it must manage its quality of service while interacting with different technologies. On the other hand, CR plays a vital role in switching from one mobile technology to another by providing flexibility in radio configuration. In 5G, CR technology is based on the design of CE which uses various approaches like nature inspired algorithm, statistical models and genetic algorithm etc. To manage resources and adaptation (selecting proper value of CR), implementation of CR in 5G is the best choice since these are few primary goals to achieve in 5G which can only be achieved with the help of CR. 5G network must have the capability for taking real time decision which can be achieved through better allocation of resources in the network and is also referred as intelligent system capability.

It is believed that future 5G system will meet many rigorous requirements related to cost, energy and productivity, associated gadgets and quiescence. CR is one of the solutions to achieve these requirements by avoiding underutilized approaches like microwave frequencies where there is a critical shortage of useable frequencies. CR has the methods and applications to extend its frameworks from conventional cell to D2D (Device to Device) and V2V (Vehicle to Vehicle) correspondence framework through underlay and overlay dynamic range access. CR can improve the functionality of the system through permission for artful and shared range access in cell frameworks. In D2D frameworks, for an efficient communication there is a requirement of large short range availability which is achieved through utilizing CR. Similarly, CR methods can be managed and applied in vehicular applications e.g. autos without drivers, particularly in the street movement which ultimately add in accomplishing the zero-mischance objective without bounds ITS (Insightful Transport Frameworks). Furthermore, for heterogeneous system (HetNet), Cognitive Radio may be utilized to latency tolerant information activity to different levels and RATs (Radio Access Advancements) which will be successful to extenuate the blockage of movement. Given all the stated advantages of CR based 5G networks, there are still some difficulties which will require to be addressed. One of the major problem would be in finding the solution of making CR transmission self-sufficient in terms of power without affecting critical impedance to the essential system particularly in heterogeneous environment. In this section we review recent work related to CR for 5G networks.

The cognition cycle possesses an intelligent framework which helps decision maker to get insight of network and adapt to the dynamic condition of the network. Limited investigations on cognition cycle have been carried out from the perspective of 5G, however, an artificial approach (reinforcement learning) has been applied in this regard. In [80] Cognition cycle based 5G network is presented in which cognition cycle is embedded in a pico-cell of a base station (BS) which changes its coverage area accordingly, in order to offload traffic of macro-cell BS. However, there will be more offload traffic from the macro-cell BS if the coverage area of pico-cell is increased. Resultantly, pico-cell experiences unsuccessful packet transmission due to the lower signal-to-interference plus-noise ratio (SINR) of the nodes at the perimeter of the pico-cell. The main aim is to maintain load balance among these cells in order to achieve successful transmission. The proposed scheme deals with the low scalability in ultra-dense environment and extremely dynamic networks using operational attributes of cognitive and traffic offload. This scheme shows improvement in throughput performance and successful transmission by maintaining the load balance. In [81], best possible channel for the nodes are known through the channel assignment by the BS. It is learnt by sharing the information of channel assignment with the nodes for user association in CR based 5G network. In channel assignment operation, BS assigns an operational channel to the nodes in extremely variable (in terms of white noise and channel interference) network. In user association operation each node picks up and associates one of the BS that ensures reliable and successful transmission. The main purpose of this scheme is to allow BS of the network cell to handover its nodes to the adjacent network cells whenever inter-cell interference increases. This scheme deals with the low network capacity and improves the energy efficiency in order to enhance the overall QoS.

White spaces in the cognitive channels can be identified by the SUs through channel sensing. During the PUs' activities, channel remains occupied and SUs need to track the PUs' activities in the cognitive channel. In [82] channel sensing is performed by BS in CR based 5G network. It evaluates the probability of channel transition due to the activities performed by PU and the poor quality of the channel. Markov model is used for representation of channel quality on the basis of channel statistical information. The main purpose is to estimate PUs' occupancy of the cognitive channel and activities. The proposed scheme deals with the low network capacity in heterogeneous environment and extremely dynamic networks using operational attributes of cognitive and traffic offload. This scheme improves the spectral efficiency in order to enhance the overall QoS. There is another term with regards to channel sensing is called collaborated channel sensing. In collaborated channel sensing each SU shares its cognitive channel sensing information with fusion center (BS) for final decision in terms of channel availability. Collaborated channel sensing deals with the multipath shadowing and fading effects caused by the individual channel sensing. In [83] the cognitive capabilities are shifted from SUs to the access points by embedding the spectrum resources in BS. In this approach, individual channel sensing by SUs is not needed. This scheme addresses the limitation and shortcomings of collaborative cognitive channel sensing technique. The proposed scheme deals with the low network capacity and large signaling overhead in heterogeneous environment and extremely dynamic networks using operational attributes of cognitive and traffic offload.

In a cellular network, all nodes share spectrum resources among themselves in order to get maximum advantages out of spectrum sharing. Spectrum sharing and inter-cell interference coordination (ICIC) operations lessen the effect of co-channel and inter-cell interference. In [84] - [86], nodes are allowed to access dynamically to the licensed and unlicensed cognitive networks. Three approaches are discussed in [86] in order to achieve aforementioned scheme. Firstly, avoid using same operating channels by the adjacent nodes and overlapping cells. The other approach is to back-off so that cellular nodes (non-contention based) do not interfere with the WiFi nodes (contention based). Lastly, dealing with the dynamic activities of WiFi networks which creates impediment for cellular networks, hence, achieving impartial concurrency of various networks. The use of directional antennas and beamforming in order to mitigate co-channel interference among the cells, is also discussed in [86]. The concept of small cells for SUs is presented in [87], which allows SUs to select operating channels with greater channel capacity and lower inter-cell interference. The higher channel capacity of each operating channel results in an overall enhancement of network channel capacity, hence, increases the throughput of the CR based 5G networks. The proposed scheme deals with the low network capacity in heterogeneous environment and extremely dense networks using operational attributes of cognitive and traffic offload. This scheme is cost effective in terms of hardware. It also improves the spectral efficiency and throughput of the network. In this proposed scheme, cognition cycle is based on an algorithm, called genetic-based algorithm and is embedded in small cells of the CR based 5G networks. The functions of the proposed algorithm are to increase throughput and SINR, and to reduce inter-cell interference and hardware cost. The performance of the genetic-algorithm is evaluated by comparing it with graph theory. Numerical results confirm that genetic-algorithm outperform graph theory in terms of less number of macro-cells and greater number of small cells. In [88], user association approach is used for association of a node with network cells in order to achieve reliable and successful packets transmission in CR based 5G network. The proposed scheme deals with the low network capacity in extremely dense and co-existence of various networks using operational attributes of cognitive and traffic offload. This scheme maintains higher spectral efficiency and also enhances energy efficiency. In [84], a back-off scheme is presented to lesson-before-talk (LBT) in which each node is equipped with channel sensing capability and it backs off before transmission from unlicensed cognitive channel. The proposed scheme enhances spectral efficiency and overall improves QoS. Another spectral efficient approach with centralized controller is presented in [85]. The main function of the centralized controller is to administer the radio resources of unlicensed cognitive channels utilized by WiFi and cellular networks. The new concept of enhanced cognitive radio networks (E-CRNs) [89] is based on Spectrum Sharing (SS) and Spectrum Aggregation (SA) for 5G wireless networks. The E-CRNs jointly exploit the licensed spectrum utilized for primary user (PU) networks whereas the unlicensed spectrum aggregated from the industrial, scientific, and medical (ISM) bands. The E-CRNs provide a new paradigm for spectrum usage with efficient use of different types of frequency bands. The proposed scheme significantly improves the system performance in terms of data rate, outage probability, and spectrum efficiency (SE) which meets the requirements of future 5G wireless communication networks.

In 5G, nodes can exchange direct messages without involving BS through D2D communication. D2D communication has been formally used in 4G (LTE) communication and has already been approved by third-generation partnership project (3GPP) in 2014 [90]. The concept D2D communication in 5G is presented in [91] and [92]. The overlay and underlay schemes are used in D2D communication for the access of operating channels in cellular networks. Dedicated non overlapping orthogonal channels are assigned for cellular and D2D communication in overlay scheme to address underutilized channels in cellular networks. On the contrary, underlay D2D scheme uses same channels for cellular and D2D communications. The main purpose is to address interference issues among cellular and D2D communication. The underlay scheme is also used in [93], in order to investigate and utilize white spaces in CR based 5G vehicular network where vehicular nodes act as SUs. The proposed scheme deals with the low network capacity in extremely dense and co-existence of various networks using operational attributes of cognitive and traffic offload. This scheme maintains higher spectral efficiency and also enhances overall QoS performance.

The use of omnidirectional antennas, increases the possibilities of inter-cell interference among adjacent nodes due to the transmission in all directions. Massive MIMO, where BS is equipped with array of small-scale antennas, supports highly directional antennas with beamforming. The directional traffic can be regulated or directed in order to form sectors. It enhances channel capacity, energy efficiency as compared to omnidirectional antenna and coverage area. In [94], two neighbouring nodes with multiple antennas are connected through a link represented by beam and operating channel in CR based 5G network. The main purpose is to establish a link using narrow beam for highly directional data transmission. The proposed scheme deals with the low network capacity in extremely dense and co-existence of various networks using operational attributes of cognitive and traffic offload. In this scheme a sensor is used by the node to track the neighbouring mobile node in order to establish a link using narrow beam. This approach improves latency rate of the network and reduces overheads due to re-beamforming.

Data plane and control plane can be accessed at one time as it is used in CR networks, by the cells or nodes of the communication network. In [94], pico-cells are used for communication network in which data plane uses mm-Wave radio access network for transmission whereas low frequency radio access network is used by control plane. The proposed scheme deals with the low network capacity in extremely dense and co-existence of various networks using operational attributes of cognitive and traffic offload. The proposed scheme improves latency rate and transmission probability.

Scheduling is a technique used for allocation of radio or network resources to the nodes and cells of communication networks. At various granularities, more than one scheduler can be assigned for allocation of resources. In [95], more than one (two) schedulers are assigned for transmission at various time granularities in CR based 5G network. The two schedulers called, centralized scheduler and distributed scheduler. The former with greater time slot, is embedded in the control plane of the main networks and latter with shorter time slot is embedded in the data plane of BSs. The basic purpose is to increase the data rate of the BSs. The proposed scheme deals with the large signaling overheads in extremely dense and co-existence of various networks using virtualization operational attributes of cognitive and network.

This scheme improves the throughput and lessen the queue length. Another scheme to avoid co-channel interference among the nodes of the networks is presented in [96]. In the proposed approach, a small cell with multiple antennas is separated into exterior and interior regions, where exterior region is further divided into small sectors. An antenna is provided to each sector. Two schedulers, spatial scheduler with longer time slot and medium access control (MAC) scheduler with shorter time slot, are assigned in order to enhance the transmission rate of the BS. The former is embedded in the BS whereas latter is embedded in the antenna of the sector. The proposed scheme deals with the large signaling overheads in extremely dense and co-existence of various networks using virtualization operational attributes of cognitive and network.

Energy efficiency is anticipated one of the challenge for future 5G networks. It plays an important role especially for networks with small cells and increases self-sustainability of nodes. Energy harvesting from various ambient sources like sun, moon, wind and vibration helps in accumulation or conservation of energy. In CR based 5G networks, the inherent CR operations such as channel sensing and dynamic channel access, reduces the overall energy efficiency of the network. In [97], nodes in a network, adapt the transmission power levels as per the requirement based on SINR. The main purpose of this scheme is to maintain a balance between the energy accumulation and energy consumption. To convert ambient field into power, spatio-temporal response of the ambient source is used. The proposed scheme deals with the spectral and energy efficiency in extremely dense and co-existence of various networks. However, energy efficiency depends on overall architecture of a network, number of users (traffic load) and the level of QoS to achieve.

The studies on CR based 5G networks have been restricted to the simulation and theoretical work. Platform implementation of 5G networks especially areas related to physical layer have been discussed in literature. Some of these areas include MIMO [98], channel modelling [99], modulation [100], physical-layer security [101], beamforming [102] and blind separation [103]. However, aspects related to networking and platform implementation are also investigated in literature. In [104], a 5G transceiver is modelled on SDN platform. It is based upon IEEE 802.15.4k direct sequence spreading spectrum (DSSS) physical (PHY) [105]. It consumes very less power and offers long-range transmission suitable for 5G communication, especially in M2M communication. CR is incorporated to explore the white spaces of the spectrum by SUs in order to achieve spectral efficiency.

The architecture comprises of three universal software radio peripheral (USRP)/ GNU radios, two SUs and a PU. Real-time signal processing operation is carried out through radio units. USRP / GNU radio is responsible for channel sensing and channel access operations whereas architecture of transceiver includes two chains viz: transmit chain and receive chain. The transmit chain performs functions related to transmission whereas receive chain performs all functions related to reception. In [106], an SDN platform is presented which is based on MAC protocol. In proposed scheme Q-learning is used to perform transmission power distribution by femtocell of BSs. MAC protocol assists femtocell in this process of power allocation. The proposed platform comprises six USRP/ GNU radios, including three BSs and three nodes. Three BSs include two femtocells and one macro-cell BSs. Likewise, three nodes include two femtocells and one macro-cell nodes. The aforementioned radio units perform MAC functions, power distribution using Q-learning, physical-layer operations and SNIR estimation. The proposed approach improves the network capacity within femtocells and lessen the inter-cell interference among macro-cells.

The concept of SDN as discussed earlier, is one of the latest concept and efforts are in hand to explore the combination of SDN with cellular networks. A scheme is proposed in [107] which optimizes the packet forwarding path and manages traffic load in dense CR based 5G network. The proposed platform is based on distributed mobility management (DMM) protocols and structured in SDN. In this scheme, control plane and data plane are kept separated, managing the functions of centralized location/ handover and packet forwarding allocation. In [108], authors present a collaborative scheme to combine SDN controller with dispersed sensors and BS of a cellular network. The proposed scheme is different from the conventional CR based systems in which device level spectrum sensing techniques are used. In SDN-based Spectrum sharing technique information is collected and integrated through dispersed sensor devices in the cellular networks. The proposed scheme addresses the issues related to inaccurate reporting and vulnerability to the malicious devices. An investigation to address the issues related to coverage, connectivity and computing of massive data generated by extremely dense environment is presented in [109]. The proposed approach presents CR-NOMA based platform comprises of femtocells to mitigate the inter-cell interference in a dense and co-existence of various networks. In order to meet the future communication network requirement especially spectrum sharing or spectrum efficiency, wider coverage, higher capacity and low latency, CR based 5G technology is the focal area for research [18]-[21]. The realization of the 5G technology is associated with the optimization of the spectrum through efficient utilization of resources in CR domain.

VII. Conclusion

Mobile Wireless Communication Technology will be the technology of future and will revolutionize the mobile market. It is also anticipated that 5G will introduce the concept of super core in which, irrespective of access technologies, all service providers will be linked up with single core through one single infrastructure. 5G is expected to overcome the limitations of existing cellular networks such as low data rate, high latency rate, low capacity, low spectral efficiency and high signaling overheads. CR technology is very promising in order to address the incompatibility between demand and supply. Hence, it will assure the balance between demand and supply to meet the requirement of its associated future technology. Resource assurance of spectrum sharing will support and encourage the development of 5G technology. CR plays a pivotal role in future 5G networks technology by incorporating its flexibility and adaptability with the speed (high data rate) of 5G. This paper presents thorough survey of recent work on CR and 5G technologies. Few inherent implementation complexities in 5G technology have been discussed with the proposed solutions investigated in recent works. Various spectrum sensing techniques are also evaluated to get the knowledge of the scope of each sensing algorithm. Finally, a comprehensive review of recent work on CR based 5G is presented. We hope that this work will motivate researchers to further excel in development of CR based 5G technology.

References

[1] J.G. Andrews, S. Buzzi, W. Choi, S. V. Hanly, A. Lozano, A. C. K. Soong and J. C. Zhang, "What will 5G be," IEEE Journal on Selected Areas in Communications, vol. 32, no. 6, pp. 1065–1082, 2014.

[2] D. Choudhury, "5G wireless and millimeter wave technology evolution: An overview" 2015 IEEE MTT-S International Microwave Symposium, 2015.

[3] Naser Al-Falahy and Omar Y. Alani, "Technologies for 5G Networks: Challenges and Opportunities," Journal IT Professional, vol.19, no.1, pp. 12-20, 2017.

[4] A. Guidotti, A. Vanelli-Coralli et al. "Architectures and Key Technical Challenges for 5G Systems Incorporating Satellites," 2018. [Online]. Available: https://arxiv.org/pdf/1806.02088.pdf

[5] V. Samuthira Pandi, J. Lakshmi Priya, "A survey on 5G mobile technology," 2017 IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), 2017.

[6] A. Gupta and R. K. Jha, "Survey of 5G Network: Architecture and emerging Technologies," IEEE Access, vol.3, pp.1206-1232, July 2015.

[7] R.S. Yarrabothu, "A Survey Paper On 5G Cellular Technologies - Technical & Social Challenges," vol. 11, pp. 98–100, June 2015.

[8] Trung Q. Duong, and Nguyen-Son Vo, "Editorial: Wireless Communications and Networks for 5G and Beyond," Mobile Networks and Applications journal, vol. 24, no. 2, pp 443–446, 2019.

[9] L. Zhang, G. Zhao, W. Zhou, L. Li, G. Wu, Y. C. Liang, and S. Li, "Primary channel gain estimation for spectrum sharing in cognitive radio networks," IEEE Trans. Commun., vol. 65, no. 10, pp. 4152–4162, Oct. 2017.

[10] Xi Zhang and Jingqing Wang, "Heterogeneous Statistical QoS Provisioning Over Cognitive-Radio Based 5G Mobile Wireless Networks," Handbook of Cognitive Radio, 2017. [Online].Available:https://link.springer.com/content/pdf/10.1007/978-981-10-1389-8_21-1.pdf

[11] C. Tsinos, F. Foukalas, and T. A. Tsiftsis, "Resource allocation for licensed/unlicensed carrier aggregation MIMO systems," IEEE Trans. Commun., vol. 65, no. 9, pp.3765–3779, Sept. 2017.

[12] P. De and S.Singh, "Modified Random Forest Approach for Resource allocation in 5G Networks," IJACSA, vol.7. no.11, 2016.

[13] S. Men, Pascal Chargé et al, "Wideband signal detection for cognitive radio applications with limited resources," EURASIP Journal on Advances in Signal Processing, 2019.

[14] RamziSaifan, Iyad Jafar, and Ghazi Al Sukkar, "Optimized Cooperative Spectrum Sensing Algorithms in Cognitive Radio Networks," The Computer Journal, vol. 60, no. 6, pp. 835–849, 2017.

[15] Ioanna Kakalou, Danai Papadopoulou et al, "A survey on spectrum sensing algorithms for cognitive radio networks," 2018 7th International Conference on Modern Circuits and Systems Technologies (MOCAST), 2018.

[15] H Kang, SK Choi. 2006. Turbulence modeling of compound open-channel flows with and without vegetation on the floodplain using the Reynolds stress model. Adv Water Resource. 29:1650–1664.

[16] Hurmat Ali Shah and I. Koo, "Reliable Machine Learning Based Spectrum Sensing in Cognitive Radio Networks," Wireless Communications and Mobile Computing journal, vol. 2018, pp.17, 2018.

[17] S. Haykin, “Cognitive Radio: Brain-Empowered Wireless Communications,” IEEE Journal on Selected Areas in Communications, vol. 23, no. 2, February 2005.

[18] Xin Liu, Y. Wang et al., "Spectrum Resource Optimization for NOMA-Based Cognitive Radio in 5G Communications,” IEEE Access, vol.6, pp. 24904 – 24911, 2018.

[19] Lu Lv, Jian Chen et al., "Cognitive Non-Orthogonal Multiple Access with Cooperative Relaying: A New Wireless Frontier for 5G Spectrum Sharing,” IEEE Commun. Mag., vol.56, no.4, pp. 188 - 195, 2018.

[20] J. Ghosh, D. N. K. Jayakody, and M. Qaraqe, "Downlink capacity of OFDMA-CR based 5G femtocell networks,” Physical Communication journal, vol. 29, pp. 329-335, 2018.

[21] Z. Song, Xin Wang et al., "Joint Spectrum Resource Allocation in NOMA-based Cognitive Radio Network with SWIPT,” IEEE Access, vol.7, pp. 89594 - 89603, 2019.

[22] C. Zhai, H. Chen, X. Wang, and J. Liu, “Opportunistic spectrum sharing with wireless energy transfer in stochastic networks,” IEEE Trans. Commun., vol. PP, no. 99, 2017.

[23] G. Sai Nitesh and Ashna Kakkar, “Generations of Mobile Communication,” International Journal of Advanced Research in Computer Science and Software Engineering, vol.32, 2016.

[24] C . Ha , K. Gua and L. Sun, “ Efficient Cooperative Spectrum Sensing Methods for Cognitive Radio Networks,” ICDMA, June 2011.

[25] Kaur, K., Kumar, and S. Baliyan, “5G: a new era of wireless communication,” International Journal of Information Technology, pp 1–6, 2018.

[26] A.-A. A. Boulogeorgos et al. “Terahertz technologies to deliver optical network quality of experience in wireless systems beyond 5G,” IEEE Commun. Mag., vol. 56, no. 6, pp. 144–151, June 2018.

[27] IEEE Standard for High Data Rate Wireless Multi-Media Networks– Amendment 2: 100 Gb/s Wireless Switched Point-to-Point Physical Layer, IEEE Standard 802.15.3d, 2017.

[28] K. L. Bhawan, and Janpath, “5G-Key Capabilities & Applications,” A study paper FN Division, TEC, March, 2019. [Online]. Available:http://tec.gov.in/pdf/Studypaper/5G%20Study%20Paper-approved%20by%20Sr%20DDG.pdf

[29] Baiqing Zong , Chen Fan, et al., “6G Technologies: Key Drivers, Core Requirements, System Architectures, and Enabling Technologies,” IEEE Vehicular Technology Mag., vol.14, no. 3, pp. 18-27, July 2019.

[30] Ping Yang, Yue Xiao, et al., “6G Wireless Communications: Vision and Potential Techniques IEEE Network, vol.33, no. 4, pp. 70-75, Jul/ Aug, 2019.

[31] L. Li, Y. Li, and R. Hou, “A novel mobile edge computing-based architecture for future cellular vehicular networks,” in Proc. IEEE Wireless Commun. Netw. Conf., San Francisco, CA, USA, pp. 1–6, 2017.

[32] J. Liu, J. Wan, B. Zeng, Q. Wang, H. Song, and M. Qiu, “A scalable and quick-response software defined vehicular network assisted by mobile edge computing,” IEEE Commun. Mag., vol. 55, no. 7, pp. 94–100, Jul. 2017.

[33] T.Rodrigues, K.Suto, H.Nishiyama, N.Kato, and K.Temma,“Cloudlets activation scheme for scalable mobile edge computing with transmission power control and virtual machine migration,” IEEE Trans.Comput., vol. 67, no. 9, pp. 1287–1300, Sep. 2018.

[34] I. Safiulin, S. Schwarz, and M. Rupp, “Multicast beamforming capabilities of LTE MBSFN for V2X communications,” in Proc. IEEE 86th Veh. Technol. Conf., Toronto, ON, Canada, pp. 1–5, 2017.

[35] K.Wang, F.R.Yu, and H.Li, “Information-centric virtualized cellular networks with device-to-device communications, ”IEEE Trans. Veh. Technol., vol. 65, no. 11, pp. 9319–9329, Nov. 2016.

[36] P. Rost et al., “Network slicing to enable scalability and flexibility in 5G mobile networks,” IEEE Commun. Mag., vol. 55, no. 5, pp. 72–79, May 2017.

[37] T. O'Shea and N. West, “Radio machine learning dataset generation with GNU radio,” in Proc. 6th GNU Radio Conf., 2016. [Online]. Available: https://pubs.gnuradio.org/index.php/grcon/article/view/11

[38] Z. Baiqing, Z. Xiaohong, W. Jianli, L. Xiaotong, and Z. Senlin, “Photonics defined radio–A new paradigm for future mobile communication of B5G/6G,” in Proc.6th Int. Conf. Photonics, Optics and Laser Technology, pp. 155–159, 2018.

[39] “5G Technology Components” Nokia white paper, 2017 [Online]. Available: https://resources.ext.nokia.com/asset/201378

[40] Xiaohu Ge, “Ultra-Reliable Low-Latency Communications in Autonomous Vehicular Networks,” IEEE Transactions on Veh. Tech., vol. 68, no. 5, 2019.

[41] S. Buzzi, I. Chih-Lin, T. E. Klein, H. V. Poor, C. Yang, and A. Zappone, "A survey of energy-efficient techniques for 5G networks and challenges ahead," IEEE J. Sel. Areas Commun., vol. 34, no. 4, pp. 697–709, 2016.

[42] Alessio Zappone, Luca Sanguinetti, and Mérouane Debbah, "Energy-Delay Efficient Power Control in Wireless Networks," IEEE Transactions on Communications, vol. 66, no.1, pp. 418 - 431, 2018.

[43] Haris Pervaiz, O. Onireti et al., "Energy-Efficient and Load-Proportional eNodeB for 5G User-Centric Networks: A Multilevel Sleep Strategy Mechanism," IEEE Vehicular Technology Magazine, vol. 13, no.4, pp. 51 - 59, 2018.

[44] H. T. Salim Al-Rikabi, Abdul Hadi M.A. et al., "Analysis of the Efficient Energy Prediction for 5G Wireless Communication Technologies," International Journal of Emerging Technologies in Learning (iJET), vol. 14, no.8, pp. 15, 2019.

[45] Wenhua Chen, Guansheng Lv et al., "Energy-efficient doherty power amplifier MMIC and beamforming-oriented digital predistortion for 5G massive MIMO application," 2017 IEEE Asia Pacific Microwave Conference (APMC), 2017.

[46] N. Glei, and R.B. Chibani, "Power Allocation for Energy-Efficient Downlink NOMA Systems," IEEE 19th international conference on Sciences and Techniques of Automatic control & computer engineering (STA), 2019.

[47] W. OBILE, "Ericsson Mobility Report", 2016. [Online]. Available: https://mypresswire.com/log/pm_files/file_31840.pdf

[48] S. K. Tayyaba, and M. Ali Shah, "5G cellular network integration with SDN: Challenges, issues and beyond," IEEE 2017 International Conference on Commun., Computing and Digital Systems (C-CODE), 2016.

[49] Ömer Bulakci, Qing Wei et al, "Identifying 5G System Enhancements: Enabling Technologies for Multi-Service Networks," 2018 IEEE Conference on Standards for Communications and Networking (CSCN), 2018.

[50] Jun Shan Wey, and Junwen Zhang, "Passive Optical Networks for 5G Transport: Technology and Standards," Journal of Lightwave Technology, vol.37, no.12, pp. 2830 – 2837, 2019.

[51] W. Lee, T. Na, and J. Kim, "How to Create a Network Slice? - A 5G Core Network Perspective," International Conference of Advanced Commun. Tech. (ICACT), 2019.

[52] D. Liang, R.Gu et al., "Demonstration of Multi-vector Multi-standard PON Network for Network slicing in 5G-oriented Mobile Network," Asia Commun. And Photonics (ACP), 2017.

[53] J. Ha, and N. Park, "Unified Control Architecture for 5G Convergence Network," IEEE 2017 International Conference on Circuits, Devices and System, 2017.

[54] R. Li, R. Wang et al., "X-Ethernet: Enabling integrated Fronhaul/ Backhaul Architecture in 5G Networks," 2017 IEEE Conference on Standards for Commun and Networking (CSCN), 2017.

[55] M. Shafi, A. F. Molisch et al., "5G: A Tutorial Overview of Standards, Trials, Challenges, Deployment, and Practice," IEEE Journal on Selected Areas in Commun., vol. 35, no. 6, 2017.

[56] A. Manzalini, and F. Marino, "Operating Systems for 5G Services Infrastructures: Convergence between IT and Telecommunications industry structures," 2018 IEEE 87th Vehicular Technology Conference (VTC Spring), 2018.

[57] Özgû Alay, Vincenzo Mancuso et al., "End to End 5G Measurements with MONROE: Challenges and Opportunities," 2018 IEEE 4th International Forum on Research and Technology for Society and Industry (RTSI), 2018.

[58] H. Koumaras, D. Tsolkas et al., "5GENESIS: The Genesis of a flexible 5G Facility," 2018 IEEE 23rd International Workshop on Computer Aided Modeling and Design of Commun. Links and Networks (CAMAD), 2018.

[59] Sheng Zhong, Hong Zhong et al., "Networking Cyber-Physical Systems: System Fundamentals of Security and Privacy for Next-Generation Wireless Networks", Security and Privacy for Next-Generation Wireless Networks, pp.1-32, 2018.

[60] Dan Wang, Dong Chen, Bin Song, Nadra Guizani, Xiaoyan Yu, and Xiaojiang Du, "From IoT to 5G I-IoT: The Next Generation IoT-Based Intelligent Algorithms and 5G Technologies," IEEE Commun. Mag., vol.56, no.10, pp. 114–120, October 2018.

[61] Hamed Rahimi, Ali Zibaeenejad, and Ali Akbar Safavi, "A Novel IoT Architecture based on 5G-IoT and Next Generation Technologies," IEEE 9th Annual Information Technology, Electronics and Mobile Commun. Conference (IEMCON), October, 2018.

[62] S.Li, L. Da Xu, and S. Zhao, "5g internet og things: A Survey," Journal of Industrial

Information Integration, 2018.

[63] Péter. K, A. Reale, et al, "Deployment of IoT applications on 5G edge," IEEE International Conference on Future IoT Technologies (Future IoT), 2018.

[64] Nadeem Javaid, Arshad Sher, et al, "Intelligence in IoT-Based 5G Networks: Opportunities and Challenges," IEEE Commun. Mag., vol.56, no.10, pp. 94–100, October 2018.

[65] Seppo Leminen, Mervi Rajahonka, et al, "Industrial internet of things business models in the machine-to-machine context," Industrial Marketing Management Journal, 2019 [online]. Available: http://www.sciencedirect.com/science/article/pii/S0019850118308137.

[66] Yousun Hwang, and Jeasung Shin, "A Study on Management of Access in Industry IoT based 5G New Radio Standalone System," International Conference on Information and Commun. Technology Convergence (ICTC), October, 2018.

[67] Valentin Vallois, Fouad Guenane, and Ahmed Mehaoua, "Reference Architectures for Security-by-Design IoT: Comparative Study," Mobile and Secure Services (MobiSecServ) 2019 Fifth Conference, pp. 1-6, 2019.

[68] T. Bukhshi, "State of the Art and Recent Research Advances in Software Defined Networking," Wireless Commun. and Mobile Computing, vol.2017, pp.35, 2017.

[69] Aijuan Li, Wenchang Yuan, et al, "Traffic Control System Based on 5G Commun. Network," IEEE 28th International Symposium on Industrial Electronics (ISIE), June, 2019.

[70] Rongpeng Li, Zhifeng Zhao, et al, "Intelligent 5G: When Cellular Networks Meet Artificial Intelligence," IEEE Wireless Commun., vol.24, no.5, pp. 175 - 183, March, 2017.

[71] I. G. Ben Yahia, J. Bendriss, et al, "CogNitive 5G Networks: Comprehensive operator use cases with machine learning for management operations," 20th conference on Innovations in Clouds, Internet and Networks (ICIN), pp. 252 - 259, 2017.

[72] Ari Pouttu, "6Genesis – Taking the first steps towards 6G," IEEE conference Standards Commun. and Networking (CSCN) 2018. [Online]. Available: http://cscn2018.ieee-cscn.org/files/2018/11/AriPouttu.pdf.

[73] International Telecommunications Union, "Focus group on technologies for Network 2030," 2019. [Online]. Available: https://www.itu.int/en/ITU-T/focusgroups/net2030/

[74] A. S. Cacciapuoti et al., "Beyond 5G: THz-Based Medium Access Protocol for Mobile Heterogeneous Networks," IEEE Commun. Mag., vol. 56, no. 6, pp. 110–15, June 2018.

[75] E Pasche, G Rouve. 1985. Overbank flow with vegetative roughened floodplains. J Hydraulic Eng.-ASCE. 111:1262–1278.

[76] Syed Junaid Nawaz, Shree Krishna Sharma et al., "Quantum Machine Learning for 6G Communication Networks: State-of-the-Art and Vision for the Future," IEEE Access, vol. 7, pp. 46317 - 46350, 2019.

[77] R. B. Patil, K. D. Kulat, and A. S. Gandhi, "SDR Based Energy Detection Spectrum Sensing in Cognitive Radio for Real Time Video Transmission," Modelling and Simulation in Engineering Journal, vol. 2018, 2018.

[78] Aditi Gupta, and Ashish Suri, " Energy Efficient Cooperative Spectrum Sensing In Cognitive Radio: A Survey," 4 th International Conference on Recent Trends and Advancements in Engineering and Technology, 2018.

[79] Y. Arjoune and N. Kaabouch, "A Comprehensive Survey on Spectrum Sensing in Cognitive Radio Networks: Recent Advances, New Challenges, and Future Research Directions," Sensors-open access journal, 2019. [online]. Available: file:///C:/Users/Dell/Downloads/sensors-19-00126.pdf

[80] C. A. S. Franco, J. R. B. de Marca, and G. L. Siqueira, "A cognitive and cooperative SON framework for 5G mobile radio access networks," in Proc. IEEE Globecom Workshop (GC Worksh), Washington, DC, USA, pp. 1–6, 2016.

[81] Q. Zhao and D. Grace, "Transfer learning for QoS aware topology management in energy efficient 5G cognitive radio networks,"in Proc.1st Int. Conf. 5G Ubiquitous Connectivity (5GU), pp. 152–157, 2014.

[82] M. J. Piran, N. H. Tran, D. Y. Suh, J. B. Song, C. S. Hong, and Z. Han, "QoE-driven channel allocation and handoff management for seamless multimedia in cognitive 5G cellular networks, "IEEE Trans. Veh. Technol., vol. 66, no. 7, pp. 6569–6585, Jul. 2017.

[83] Z. Zhang, W. Zhang, S. Zeadally, Y. Wang, and Y. Liu, "Cognitive radio spectrum sensing framework based on multi-agent architecture for 5G networks," IEEE Wireless Commun., vol. 22, no. 6, pp. 34–39, Dec. 2015.

[84] A. Mukherjee et al., "Licensed-assisted access LTE: Coexistence with IEEE 802.11 and the evolution toward 5G,"IEEE Commun. Mag.,

vol.54, no. 6, pp. 50–57, Jun. 2016.

[85] Q. Chen, G. Yu, and Z. Ding, "Optimizing unlicensed spectrum sharing for LTE-U and WiFi network coexistence," IEEE J. Sel. Areas Commun., vol. 34, no. 10, pp. 2562–2574, Oct. 2016.

[86] R. Zhang, M. Wang, L. X. Cai, Z. Zheng, X. Shen, and L.-L. Xie, "LTE-unlicensed: The future of spectrum aggregation for cellular networks," IEEE Wireless Commun., vol. 22, no. 3, pp. 150–159, Jun. 2015.

[87] F.-H. Tseng, L.-D. Chou, H.-C. Chao, and J. Wang, "Ultra-dense small cell planning using cognitive radio network toward 5G," IEEE Wireless Commun., vol. 22, no. 6, pp. 76–83, Dec. 2015.

[88] C. Yang, J. Li, M. Guizani, A. Anpalagan, and M. Elkashlan, "Advanced spectrum sharing in 5G cognitive heterogeneous networks," IEEE Wireless Commun., vol. 23, no. 2, pp. 94–101, Apr. 2016.

[89] W. Zhang, Cheng-Xiang. W, X.Ge, Y.Chen, “Enhanced 5G Cognitive Radio Networks Based on Spectrum Sharing and Spectrum Aggregation”, IEEE Transactions on Communications, vol. xx, no. yy, 2018.

[90] Network Architecture (Release 12), document 3GPP TS 23.002 V12.6.0, Technical Specification Services and System Aspects, 2014.

[91] H. A. U. Mustafa, M. A. Imran, M. Z. Shakir, A. Imran, and R. Tafazolli, "Separation framework: An enabler for cooperative and D2D communication for future 5G networks, "IEEE Commun. Surveys Tuts., vol.18, no.1, pp. 419–445, 2016.

[92] G. Fodor et al., "An overview of device-to-device Commun. Tech. components in METIS, "IEEE Access, vol.4, pp.3288–3299, 2016.

[93] S. Mumtaz, K. M. S. Huq, M. I. Ashraf, J. Rodriguez, V. Monteiro, and C. Politis, "Cognitive vehicular communication for 5G," IEEE Commun. Mag., vol. 53, no. 7, pp. 109–117, Jul. 2015.

[94] K. Chandra, R. V. Prasad, B. Quang, and I. G. M. M. Niemegeers, "CogCell: Cognitive interplay between 60 GHz picocells and 2.4/5 GHz hotspotsinthe5Gera,"IEEE Commun. Mag., vol.53,no.7,pp.118–125, Jul. 2015.

[95] C.-F. Liu, S. Samarakoon, and M. Bennis, "Fronthaul-aware softwaredefined joint resource allocation and user scheduling for 5G networks," in Proc. IEEE Globecom Workshop (GC Worksh), Washington, DC, USA, pp. 1–6, 2016.

[96] A. A. Gebremariam, T. Bao, D. Siracusa, T. Rasveed, F. Granelli, and L.Goratti,"Dynamic strict fractional frequency reuse for software-defined 5G networks," in Proc. IEEE Int. Conf. Commun. (ICC), pp. 1–6, 2016. Heterogeneous Networks,” IEEE Commun. Mag., vol. 56, no. 6, pp. 110–15, June 2018.

[97] S. A. R. Zaidi, A. Afzal, M. Hafeez, M. Ghogho, D. C. Mclernon, and A. Swami, "Solar energy empowered 5G cognitive metro-cellular networks," IEEE Commun. Mag., vol. 53, no. 7, pp. 70–77, Jul. 2015.

[98] B. Song, Z. Wei, G. Li, X. Zhang, Y. Liu, and D. Yang, "Energy and spectral efficiency analysis of millimeter wave MIMO system based on known-position beamforming," in Proc. IEEE/ CIC Int. Conf. Commun. China (ICCC), pp. 1–6, 2017.

[99] W. Khawaja, O. Ozdemir, and I. Guvenc, "UAV air-to-ground channel characterization for mmWave systems," in Proc. IEEE 86th Veh. Technol. Conf. (VTC-Fall), pp. 1–5, 2017.

[100] J. J. H. Almeida, P. B. Lopes, and C. Akamine, "A proposal for the next generation of ISDB-TB using FBMC in a SDR implementation on GNU radio environment," IEEE Latin Amer. Trans., vol. 15, no. 7, pp. 1231–1237, 2017.

[101] N.Gao, X.Jing, S.Lv, J.Mu, and L.Sun, "Wireless physical layer characteristics based random number generator: Hijack attackers, 'in Proc. IEEE 86th Veh. Technol. Conf. (VTC-Fall), pp. 1–5, 2017.

[102] D.-W. Park, G.-H. Gwag, H.-J. Oh, I.-M. Park, and Y.-S. Eo, "28 GHz RF transceiver module for 5G beam-forming system," in Proc. Asia–Pacific Microw. Conf. (APMC), pp. 1–4, 2017.

[103] M. Yu, "The blind separation of wireless communication signals utilizing USRP," in Proc. 5th Int. Conf. Comput. Sci. Netw. Secur. (ICCSNT), pp. 677–680, 2016.

[104] X. Xiong, T. Wu, H. Long, and K. Zheng, "Implementation and performance evaluation of LECIM for 5G M2M applications with SDR, "in Proc. IEEE Globecom Workshop (GC Worksh), pp. 612–617, 2014.

[105] IEEE Standard for Local and Metropolitan Area Networks—Part 15.4: Low-Rate Wireless Personal Area Networks (LR-WPANs)—Amendment 5: Physical Layer Specifications for Low Energy, Critical Infrastructure Monitoring Networks, IEEE Standard 802.15.4k, 2013.

[106] M. H. M. Elsayed and A. Mohamed, "Distributed interference management using Q-learning in cognitive femtocell networks: New USRP-based implementation, " in Proc. New Technol., Mobility Secur. (NTMS), pp. 1–5, 2015.

[107] H. Ko, I. Jang et al. "SDN-based Distributed Mobility Management for 5G," 2017 IEEE International Conference on Consumer Electronics (ICCE), 2017.
[108] A. M. Akhtar, X. Wang, and L. Hanzo, "Synergistic spectrum sharing in 5G HetNets: A harmonized SDN-enabled approach," IEEE Commun. Mag., vol. 54, no.1, pp. 40 - 47, 2016.
[109] I. Budhiraja, S. Tyagi et al., "CR-NOMA Based Interference Mitigation Scheme for 5G Femtocells Users," 2018 IEEE Global Commun. Conference (GLOBECOM), 2018.